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SAMSO-TR 75-251 VOL I

STANFORD TELECOMMUNICATIONS, INC.
REPORT NO. STI TR 10255 VOL I

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NAVSTAR GLOBAL POSITIONING SYSTEMS SPECIAL STUDIES AND ENGINEERING PROGRAM

VOLUME I

FINAL REPORT

Prepared by:

James J. Spilker, Jr.
Lloyd Engelbrecht
Jackson T. Witherspoon

October 25, 1975

SPACE AND MISSILE SYSTEMS ORGANIZATION (AFSC)
LOS ANGELES AIR FORCE STATION
LOS ANGELES, CALIFORNIA

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This technical report has been reviewed and is approved for publication.

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AIR FORCE REPORT NO.
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VOLUME I

FINAL REPORT

GPS/SAC BOMB SCORING SYSTEM EVALUATION

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FOREWORD

This document is Volume I of a four volume report. The four volume report is titled, "NAVSTAR Global Positioning Systems Special Studies and Engineering Program". Volume I summarizes the work performed for the Air Force and specifically addresses the GPS/SAC Bomb Scoring System Evaluation. It was previously submitted in draft form on October 15, 1975, under report number STI/GPS-052.

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SECTION 1

BOMB SCORING SYSTEM EVALUATION

1.0 INTRODUCTION

1.1 General

This report describes the evaluation and comparison of three Bomb Scoring System (BSS) techniques which use the GPS satellites to assist in the accuracy assessment. The objective of each system is to provide an independent evaluation of the aircraft's navigation/bombing accuracy and is therefore supplemental to the aircraft's navigation system.

Alternate A considers the use of on-board GPS and other aircraft instrumentation to derive the evaluation. Since it uses on-board equipment, alternate A has the least impact on the aircraft's performance. It is of course limited in its application to GPS-equipped aircraft.

Alternate B considers the use of totally redundant equipment, carried in a separate BSS pod to derive the independent assessment, and is similar in nature to the GPSTP.

Alternate C considers the use of transponded data to a ground station in order to minimize the aircraft-carried equipment therefore minimizing the impact to the aircraft's performance. Prior investigation* has shown that the accuracy requirements can be achieved using this concept.

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*STI report "GPS/SAC System Concept" dated April 8, 1975.

Sections 2, 3, and 4 describe the alternates A, B, and C respectively and define the impact of each approach on the aircraft and also provide ROM cost estimates for each approach. Section 5 compares the techniques and delineates the recommendations.

1.2 Summary Conclusions

1.2.1 Alternate A

Alternate A, while being the least costly and also minimizing the impact on the aircraft, is least flexible and does not satisfy the BSS assessment capability for non-GPS equipped aircraft. It is therefore not a stand-alone solution and is not recommended.

1.2.2 Alternates B, C

Alternate C is approximately equivalent to Alternate A in its minimal impact on the aircraft, but provides for significantly improved flexibility in utilization over Alternate A. Additionally, Alternate C provides the excellent opportunity for real-time assessment, a capability not easily achieved with alternates A or B. Alternate C costs are approximately equal to Alternate B if two pods are implemented, and becomes more economical than B if more than two pods are implemented. Alternate C is the recommended approach.

	Characteristics	Alternate A (X-Set Equipped A/C)	Alternate B (X-Set in BSS Pod)	Alternate C (Transponded Signals to G.T.)
PHYSICAL	Aircraft weight power size	430 lbs. 485 watts small pod	1135 lbs. 1515 watts large pod (600 gal)	536 lbs. 480 watts small pod
OPERATIONAL	Capable of Real Time Assessment	no	no	yes(added processor required)
	Adaptable to wide variety of aircraft	no (must have X-set)	yes (must have capability of carrying pod)	yes
	Independent of Target Location	yes	yes	no (Aircraft must be in range of ground terminal: 80 nmi at 5000 ft. altitude)
PERFORMANCE	Independent Assessment	no (uses same navigation data as aircraft)	yes	yes
	Ability to Resolve Ionospheric Propagation Errors	excellent	excellent	good (requires interpolation from ground terminal/satellite geometry to aircraft/satellite geometry)
COST	1 Pod	$550 K	$1,190 K	$1,430 K
	2 Pods	$715 K	$1,735 K	$1,665 K
	3 Pods	$880 K	$2,280 K	$1,900 K

SECTION 2

2.0 ALTERNATE A - USE OF ON-BOARD X-SET DATA

2.1 System Description

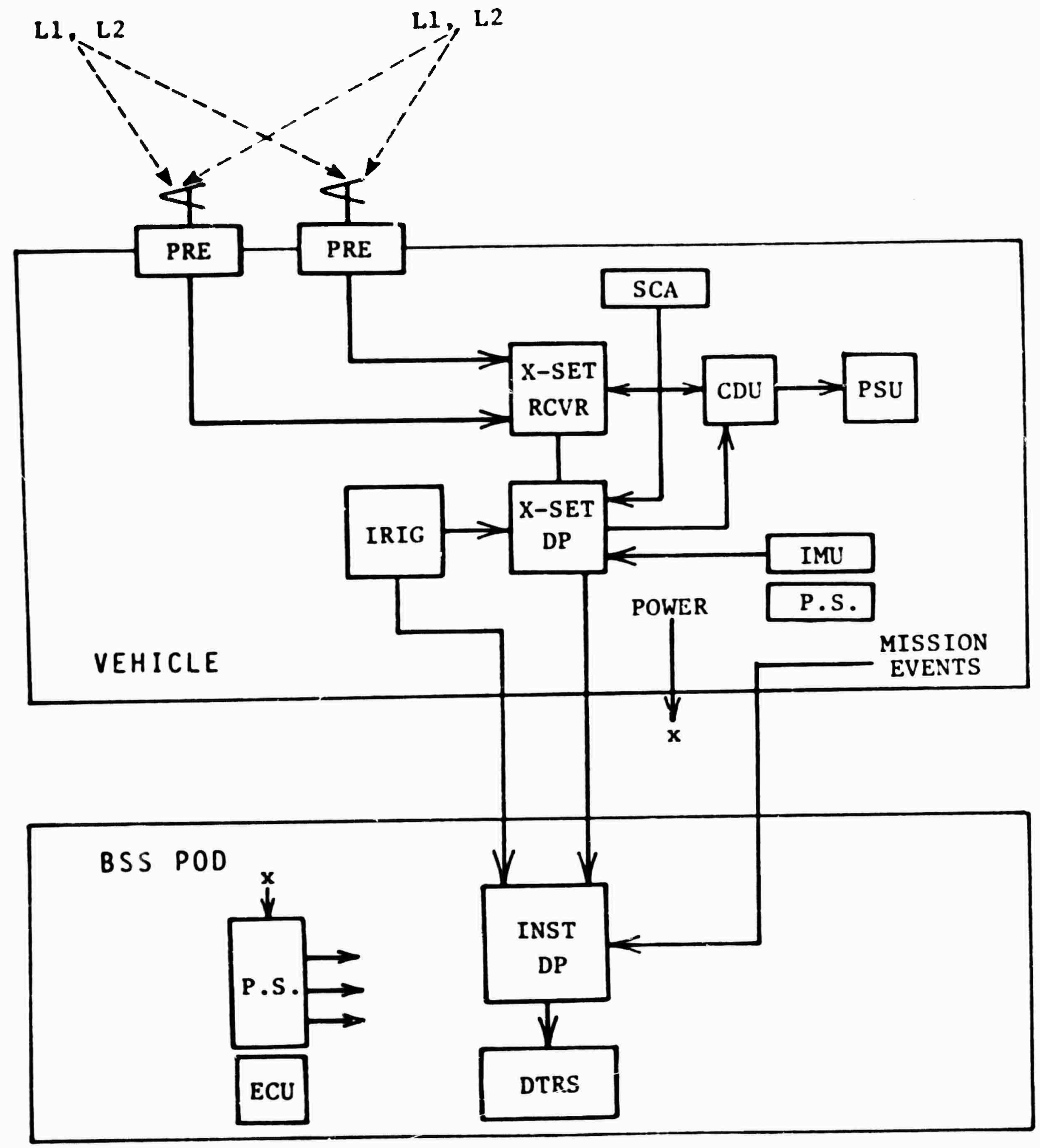
Alternate A has been considered for the Bomb Scoring System (BSS) because it requires the minimum additional hardware and aircraft modification for those aircraft already equipped with the X-set user equipment. Figure 2-1 shows the system equipment configuration.

In normal operation, the aircraft receives the L1 and L2 signals from multiple satellites to determine its position. Both L1 and L2 are received to resolve the ionospheric propagation error. Figure 2-2 shows the signal spectra. The signals are acquired by the X-set receiver, and the data and timing signals are fed to the X-set data processor. Figure 2-3 is a block diagram of the user X-set, and Figure 2-4 shows the interface of the instrumentation processor with the X-set.

The X-set processor data, the bombing mission events, and IRIG time are also fed to the instrumentation processor for formatting and then fed to the digital tape recorder.

2.2 System Characteristics

While Alternate A applications are limited to only those aircraft already equipped with the GPS/X-set equipment, the system does provide a low cost assessment capability. The system can be utilized on any selected range (i.e. the system is not "tied" to the ground station). Aircraft frame modifications are minimal in that only the interface cabling must be added.



LEGEND

PRE	-	PREAMPLIFIER
DP	-	DATA PROCESSOR
CDU	-	CONTROL DISPLAY UNIT
PSU	-	PILOT STEERING UNIT
IMU	-	INERTIAL MEASUREMENT UNIT
IRIG	-	TIME CODE GENERATOR
P.S.	-	POWER SUPPLY
DTRS	-	DIGITAL TAPE RECORDER SYSTEM
ECU	-	ENVIRONMENTAL CONTROL UNIT
SCA	-	SIGNAL CONDITIONING AMPLIFIER

FIGURE 2-1 ALTERNATE A CONFIGURATION
(Use of Vehicle X-Set)

Figure 2-2 Navigation Signals

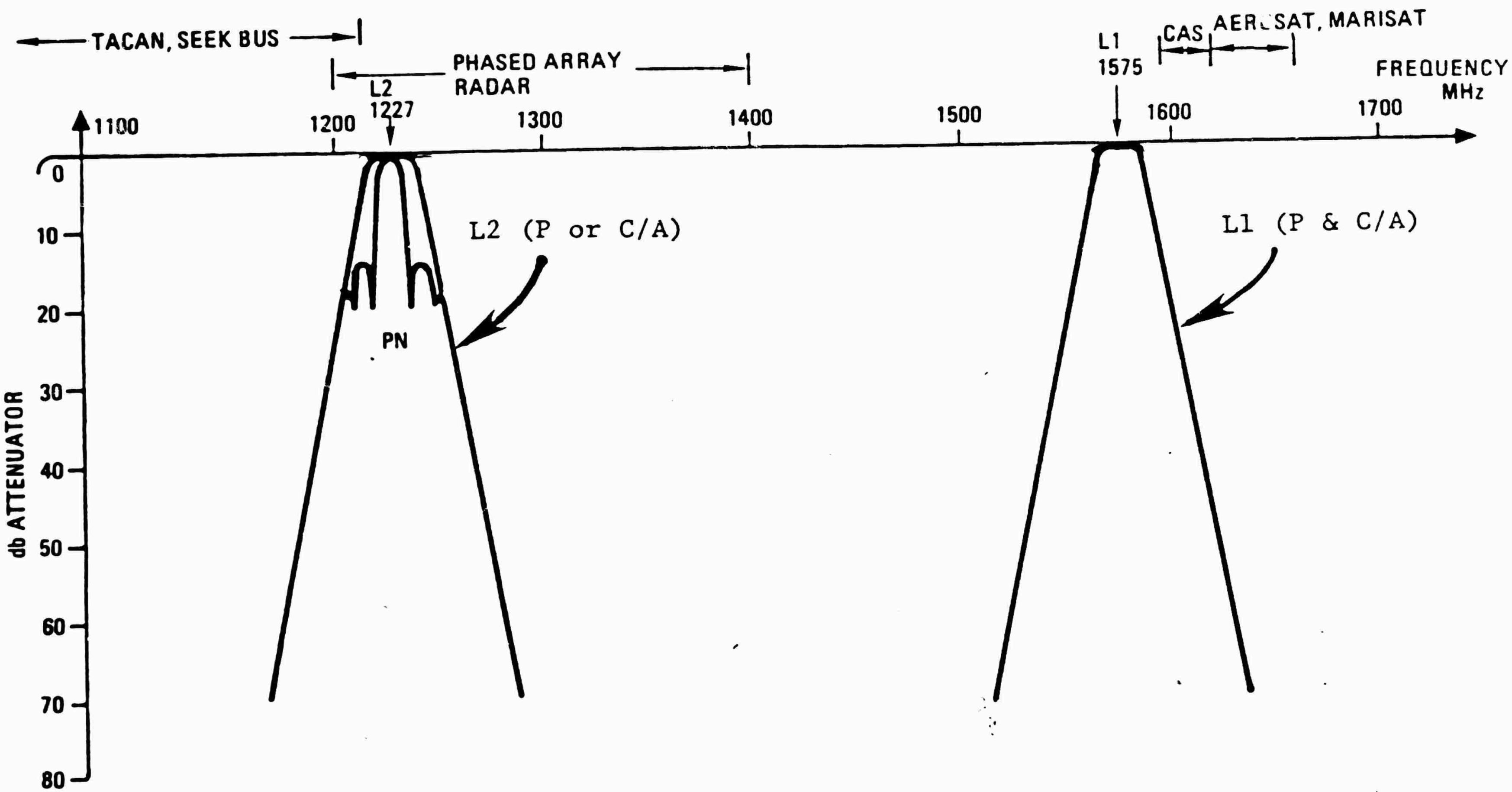


Figure 2-3

UE SET X PRIME ITEM FUNCTIONAL BLOCK DIAGRAM

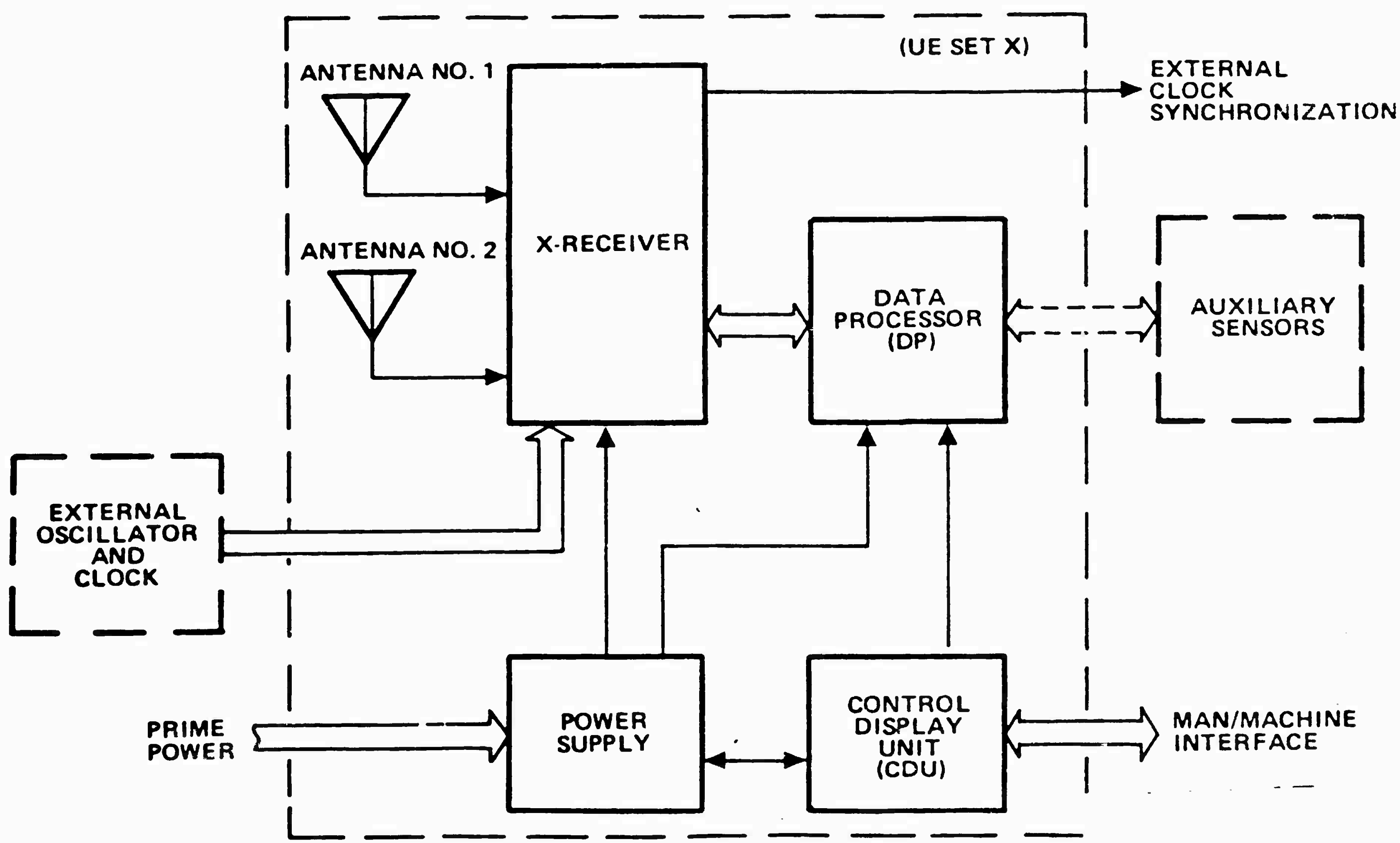


Figure 2-4

X SET (UNAIDED) USER EQUIPMENT

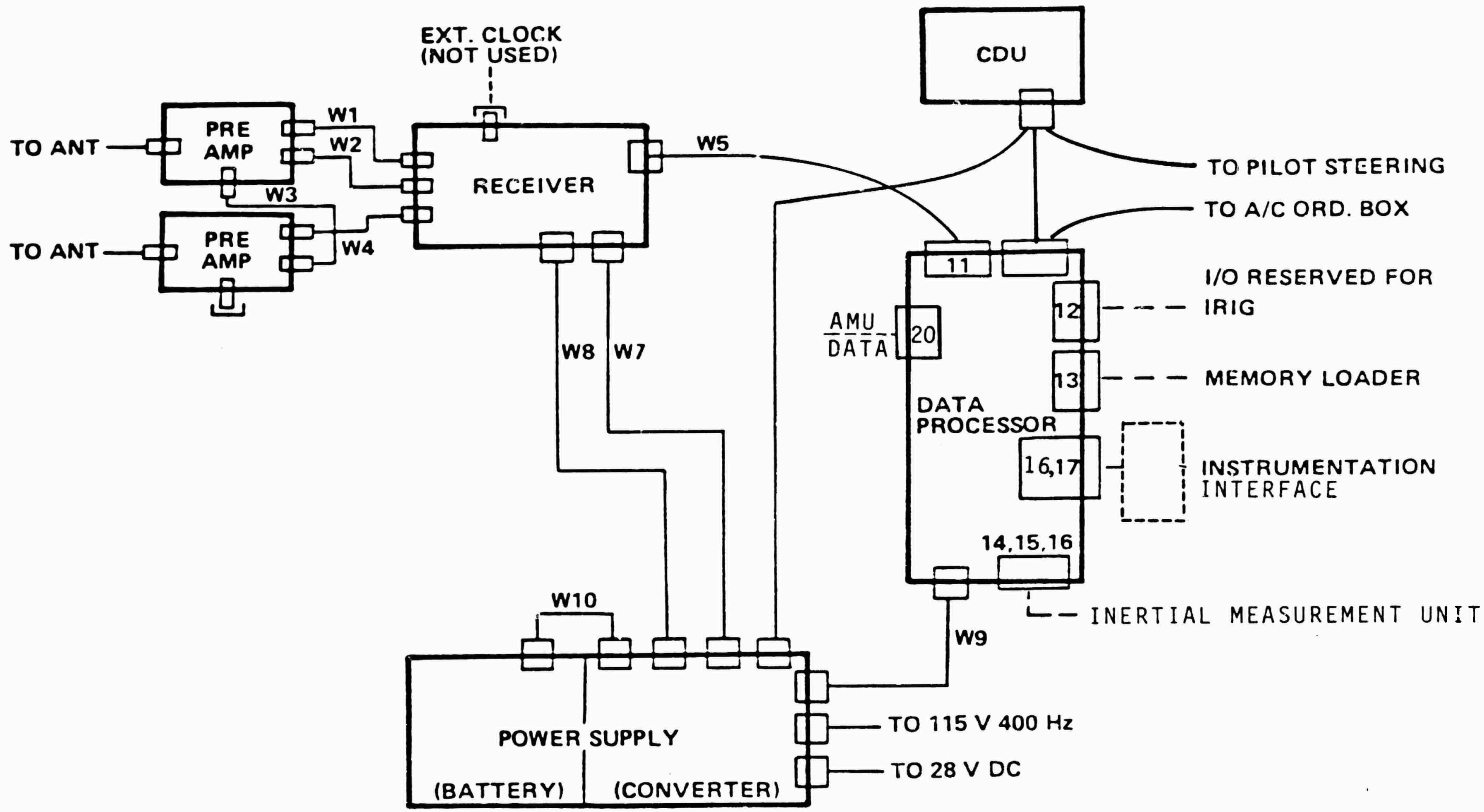


Table 2-5 summarizes the estimated weight, volume and power requirements for alternate A. Table 2-6 is a ROM cost tabulation for the implementation.

TABLE 2-5

ALTERNATE A

EFFECT ON AIRCRAFT

AIRCRAFT	WEIGHT	VOLUME	POWER
Cabling	10 lbs	300 in^3	-
BSS POD			
Instrumentation D.P	44.9 lbs	3253 in^3	175 watts
Recorder	40.1 lbs	1407 in^3	100 watts
P.S.	40 lbs	2000 in^3	200 watts
E.C.U.	40 lbs	3000 in^3	10 watts
Subtotals	165.0 lbs	9660 in^3	485 watts
Pod Hardware	25.0 lbs	-	-
Subtotals	190.6 lbs	9660 in^3	485 watts
Pod and Pod Adapter	200 lbs		-
Cables	30 lbs		-
BSS TOTAL	420 lbs		485 watts
TOTAL IMPACT	430 lbs		485 watts

TABLE 2-6

ALTERNATE A

ROM COST IMPACT

AIRCRAFT MODIFICATIONS	NON-RECURRING	RECURRING
Cabling/Install/Doc/Test	$ 10,000	$ 10,000
BSS POD		
Instrumentation D.P/Software	$100,000	$ 35,000
Recorder	10,000	25,000
E.C.U.	50,000	20,000
P.S. System/Panel	25,000	20,000
Pod Modifications/Doc.	50,000	20,000
Integrate/Install/Test	15,000	25,000
SYSTEM		
Test	$ 25,000	$ 10,000
AGE	100,000	-
TOTALS	$385,000	$165,000

SECTION 3

3.0 ALTERNATE B - X-SET IMPLEMENTATION IN GPSTP

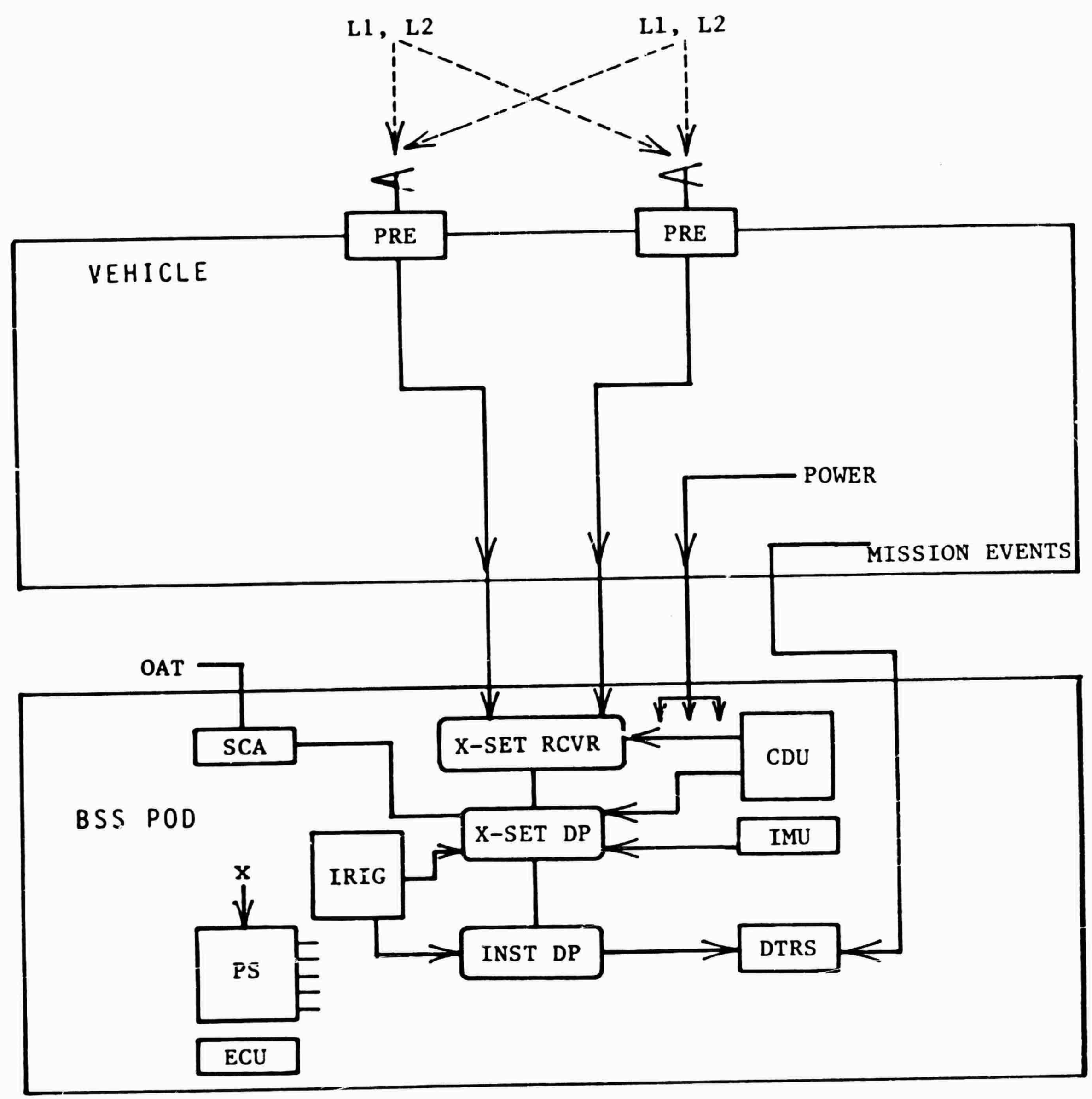
3.1 System Description

Alternate B consists of a BSS pod utilizing an X-set for independent position assessment. This alternative requires only that antennas and preamps be installed on the host aircraft for the reception of NAVSTAR L1 and L2 signals. Figure 3-1 shows the Alternate B configuration which is essentially the same configuration as the GPSTP configuration.

The L1 and L2 signals are received via antennas and preamplifiers installed on the host vehicle. These signals, plus power, and bomb release data are fed to the BSS pod. The BSS pod contains the user X-set equipment, the inertial measurement unit, air temperature sensor for the air mass measurement, IRIG time, the instrumentation processor, and digital tape recorder. Additionally, a power supply subsystem and environmental control unit are required.

3.2 System Characteristics

Alternate B is applicable to a wide variety of aircraft whether equipped with GPS navigation equipment or not, and additionally, this alternative is not constrained to a range limitation (i.e. system is not "tied" to a ground station). Table 3-2 is a summary of the weight, volume, and power impact and Table 3-3 is a ROM estimate of the System's implementation.



LEGEND

OAT	-	OUTSIDE AIR TEMPERATURE
PRE	-	PREAMPLIFIER
DP	-	DATA PROCESSOR
CDU	-	CONTROL DISPLAY UNIT
PSU	-	PILOT STEERING UNIT
IMU	-	INERTIAL MEASUREMENT UNIT
IRIG	-	TIME CODE GENERATOR
P.S.	-	POWER SUPPLY
DTRS	-	DIGITAL TAPE RECORDER SYSTEM
ECU	-	ENVIRONMENTAL CONTROL UNIT
SCA	-	SIGNAL CONDITIONING AMPLIFIER
MUX	-	MULTIPLEXER

FIGURE 3-1 ALTERNATE B CONFIGURATION
(X-Set Supplied in BSS POD)

TABLE 3-2

ALTERNATE B

CHARACTERISTICS

AIRCRAFT	WEIGHT	VOLUME	POWER
Antenna/Preamp	30 lbs	700 in^3	3 watts
BSS POD			
X-Set (Total)	226 lbs	9,338 in^3	775 watts
Instrumentation D.P.	45 lbs	3,253 in^3	175 watts(est)
IRIG TEG	15 lbs	973 in^3	40 watts
I.M.U.	34 lbs	1,496 in^3	100 watts(est)
DTRS	41 lbs	1,407 in^3	100 watts
DAT/SCU	2 lbs	12 in^3	1 watt
Subtotal	363 lbs	16,479 in^3	1190 watts
P.S.S	90 lbs	4,400 in^3	300 watts
E.C.U.	120 lbs	8,000 in^3	20 watts
Pod Hardware	85 lbs		-
Subtotal	658 lbs	28,879 in^3	1510 watts
Pod/Pod Adapter	385 lbs	-	-
Cables	60 lbs	-	-
POD TOTAL	1103 lbs		1510 watts
AIRCRAFT TOTAL	1133 lbs		1513 watts

TABLE 3-3

ALTERNATE B

ROM COST IMPACT

Aircraft Frame	Non-Recurring	Recurring
Ant/Install	$ 50,000	$ 10,000
Reamp/Install	-	30,000
Intg/DOC	20,000	-
Test	10,000	5,000
BSS POD		
X-Set	-	150,000
Inst. D.P. (Soft)	100,000	35,000
IMU	-	100,000
DTRS	10,000	25,000
IRIG TCG	-	20,000
OAT/SCA	-	10,000
ECU	50,000	30,000
P.S. SYSTEM/PANEL	30,000	25,000
POD MODIF/DOC	150,000	40,000
INTEG/INSTALL/TEST	35,000	40,000
SYSTEM		
TEST	40,000	25,000
AGE	150,000	-
TOTAL	$645,000	$545,000

SECTION 4

4.0 ALTERNATE C - TRANSPONDED SIGNALS

4.1 System Description

Figures 4-1 (a) and (b) are block diagrams of a Bomb Scoring System utilizing aircraft and navigation data transponded to a ground station. The satellite L1 and L2 signals are received by the ground stations to precisely determine its position, and the signals are also used as reference signals for the aircraft relayed navigation signals.

The aircraft receives the L1 signals, amplifies and frequency translates them, and transmits the signals to the ground station. The differential delay of each signal relative to the direct signal permits the ground station to compute the aircraft's position.

Additionally, the ground station transmits a low UHF signal to the aircraft which is also transponded back to the ground station at S-Band. This signal permits the recording of the doppler frequency shift. (Alternately, a PN sequence can be utilized on the turnaround channel to permit range and range rate determination).

The transponder, in addition to having a UHF transponded channel and the C/A transponded channels, has a beacon carrier. This beacon channel can be amplitude modulated with aircraft flight data.

The transponder described is being developed for missile tracking and should be well suited to this BSS application. Figure 4-2 shows the frequency translation of this Multiband Frequency Translator.

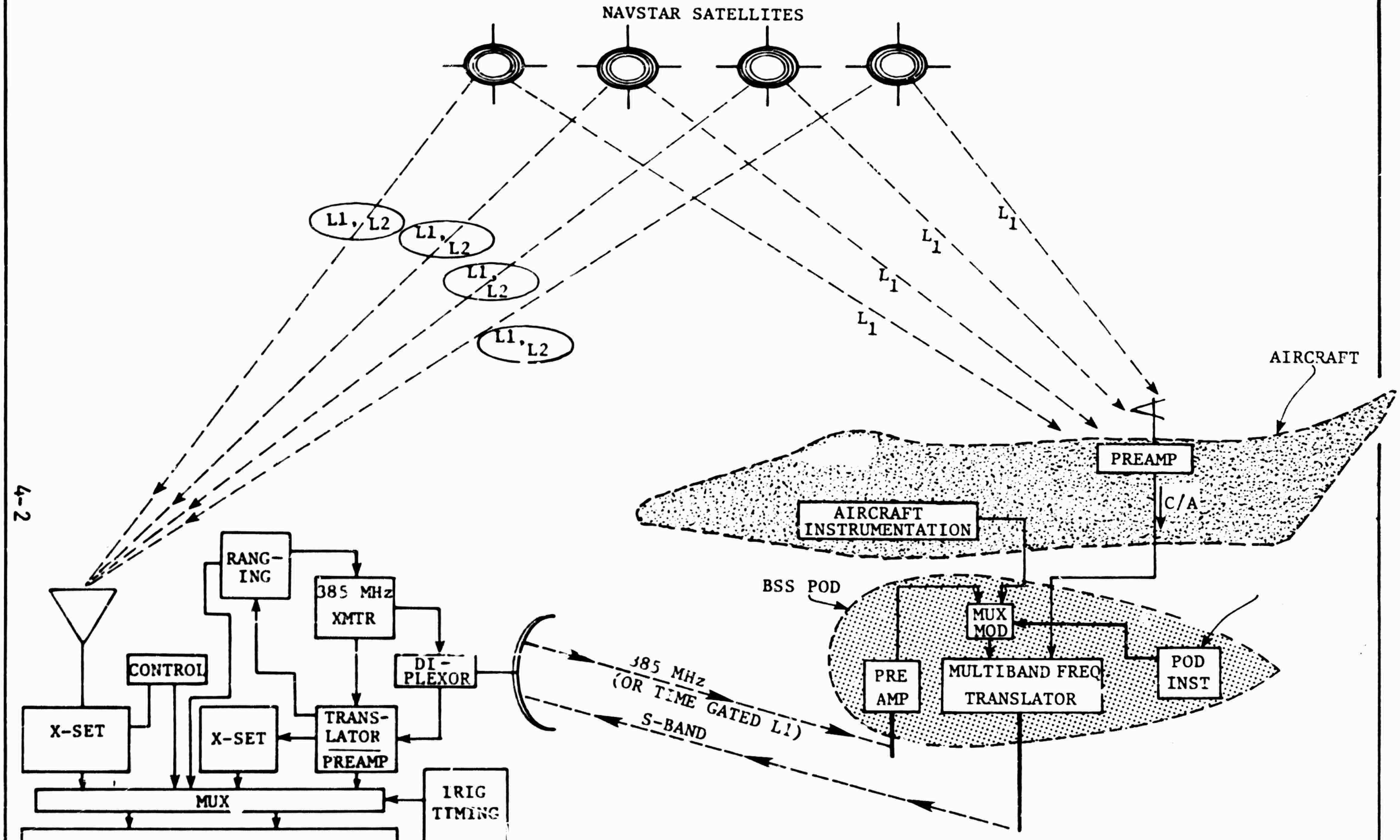
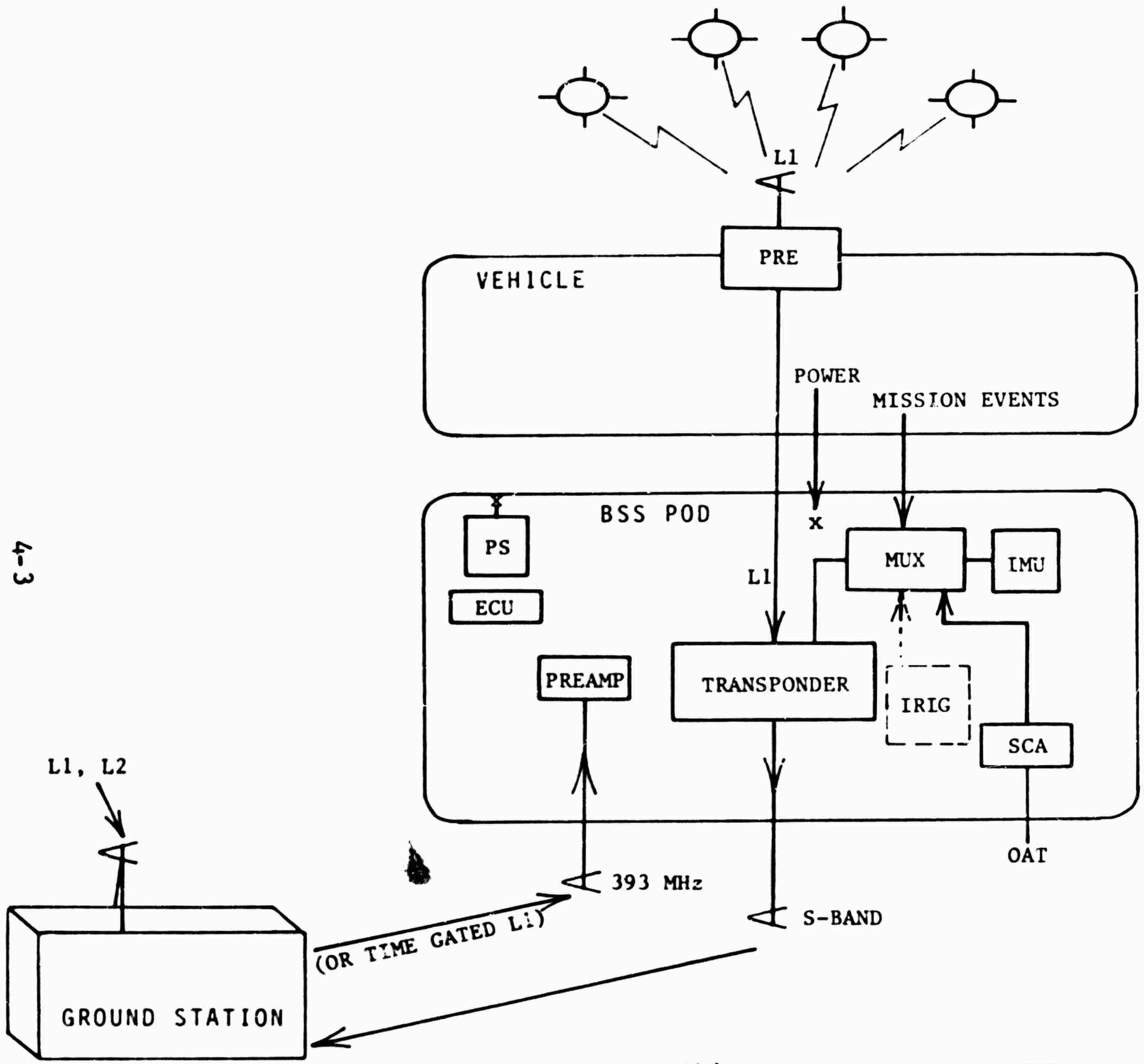


FIGURE 4-1-(a)
ALTERNATIVE C CONFIGURATION
(TRANSPONDED NAVIGATION DATA)



LEGEND

OAT	- OUTSIDE AIR TEMPERATURE
PRE	- PREAMPLIFIER
DP	- DATA PROCESSOR
CDU	- CONTROL DISPLAY UNIT
PSU	- PILOT STEERING UNIT
IMU	- INERTIAL MEASUREMENT UNIT
IRIG	- TIME CODE GENERATOR
P.S.	- POWER SUPPLY
DTRS	- DIGITAL TAPE RECORDER SYSTEM
ECU	- ENVIRONMENTAL CONTROL UNIT
SCA	- SIGNAL CONDITIONING AMPLIFIER
MUX	- MULTIPLEXER

FIGURE 4-1(b) ALTERNATE C CONFIGURATION
(Transponded Navigation Signals)

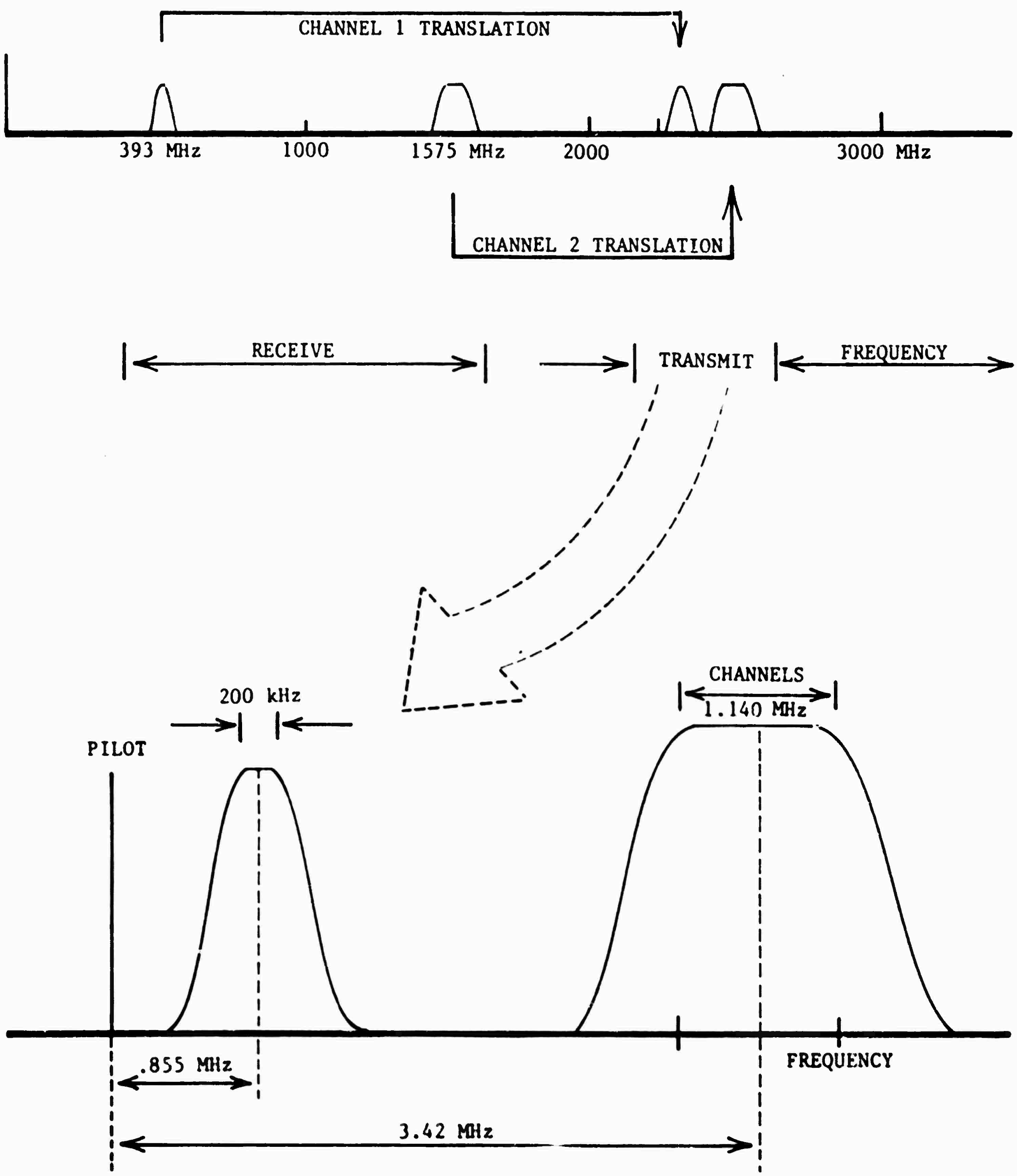


FIGURE 4-2 MULTIBAND FREQUENCY TRANSLATOR FREQUENCY PLAN

As an alternate to the UHF, a time-gated or CW signal can be used at L1. STI has recently completed a GPS study for this type of operation. The recommended codes have been less than -40 dB cross-correlation with respect to the GPS C/A codes.

4.2 System Characteristics

Figure 4-3 shows the information flow for this alternative. Satellite navigation data, aircraft telemetry (dynamics), and the ground originated navigation data provide the data base for assessing the aircraft's position. This data is totally independent of the aircraft's navigation system. The prime aircraft modification is to add an antenna/preamp on the aircraft frame for the reception of the NAVSTAR signals.

No X-set is required in the aircraft for the position determination; an X-set at the ground terminal serves this function. There is also the potential of deleting a time standard in the pod instrumentation, especially if ground ranging is utilized. A tabulation of Alternative C impact on the aircraft is given in Table 4-4.

This alternative also has potential advantage in that it is feasible to accomplish real time BSS processing at the ground station through the addition of a processor.

Because only the C/A L1 signal can be transponded by the aircraft, the ground terminal must use interpolation from its direct L1/L2 signals to reserve the transponded signal's ionspheric propagation error. Because the spacecraft/ground geometry does not significantly change between the satellite to ground terminal and the satellite to aircraft, little error is expected in the interpolation. The nominal terrestrial range with a 5000 ft. aircraft altitude is approximately 80 nautical miles.

A ROM cost estimate has been made for this alternative C and this data is given in Table 4-5.

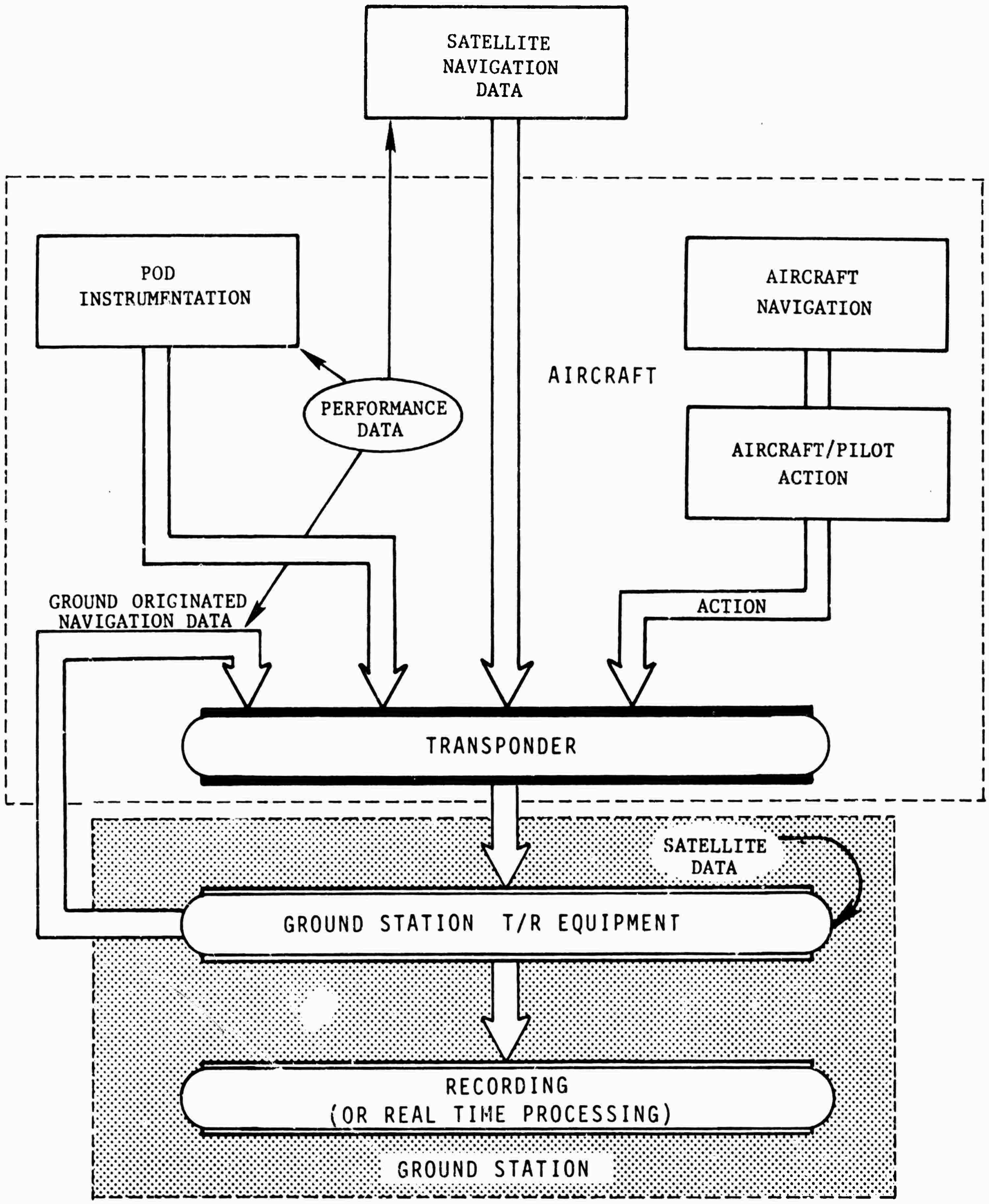


FIGURE 4-3 ALTERNATE C INFORMATION FLOW

TABLE 4-4
ALTERNATE C CHARACTERISTICS

AIRCRAFT	WT.	VOL.	POWER
Preamp/Antenna	15 lbs	350 in^3	1.5 watts
BSS POD			
Multiband Translator	65 lbs	3,456 in^3	150 watts
IMU	34 lbs	1,496 in^3	100 watts
OAT/SCA	2 lbs	12 in^3	1 watt
Multiplexer	15 lbs	1,250 in^3	15 watts
Modulator	15 lbs	350 in^3	2 watts
Sub Total	131 lbs	5,864 in^3	268 watts
PSS	35 lbs	2,000 in^3	200 watts
ECU	40 lbs	3,000 in^3	10 watts
Sub Total	206 lbs	10,864 in^3	478 watts
POD Hardware	30 lbs		
	236 lbs		
POD & POD Adapt.	250 lbs		
Cables	35 lbs		
BSS POD TOTAL	521 lbs		478 watts
TOTAL IMPACT	536 lbs		480 watts

TABLE 4-5

ALTERNATE C

ROM COST IMPACT - VEHICLE

	NON-RECURRING	RECURRING
AIRCRAFT		
Ant/Install.	$ 50,000	$ 10,000
Preamp/Install.		15,000
Integ/Doc.	20,000	
Test	10,000	5,000
BSS POD		
Multiband Translator		35,000
IMU	10,000	25,000
Multiplexer/Modulator	40,000	20,000
OAT/SCA		10,000
Preamp (UHF)		5,000
ECU	50,000	20,000
PS System/Panel	25,000	20,000
POD Modif/Doc.	50,000	20,000
Integ/Install/Test	15,000	25,000
AGE	100,000	-
TOTAL (VEHICLE)	$370,000	$210,000

TABLE 4-5 (Continued)
ALTERNATE C
ROM COST IMPACT-GROUND TERMINAL

GROUND TERMINAL		NON-RECURRING	RECURRING
X-Set & Antenna			$150,000
X-Set			150,000
Translator		$ 25,000	10,000
Ranging		25,000	15,000
UHF Source			10,000
MUX		40,000	15,000
IRIG TRG			20,000
DTRS		10,000	25,000
Ant/Tracker		5,000	25,000
Shelter/Modif.		25,000	10,000
Integ/Install/Doc.		75,000	75,000
P.S. System		5,000	25,000
Test		20,000	25,000
		$230,000	$555,000
SYSTEM			
Test		40,000	25,000
TOTALS	(Vehicle)	370,000	210,000
	(G.T.)	230,000	555,000
	Test	40,000	25,000
		$640,000	$790,000

SECTION 5

5.0 ALTERNATE COMPARISON & RECOMMENDATIONS

5.1 Comparison

A tabulation and comparison of key features of the three alternatives is given in Table 5-1. Alternate A appears to have the minimum impact on aircraft weight and power, can utilize a smaller pod, and is the least costly, however, it is also the least flexible in that it is only applicable to X-set equipped aircraft. It also provides the least independent data for scoring assessment.

Alternative B has the highest weight and power impact on the aircraft, requires a larger pod, and also appears to be the most costly. However, it is a flexible approach since it is applicable to any aircraft evaluation (not just those equipped with the GPS navigation system) and does not have a range limitation. For those applications where the prime mission navigation equipment is also in a pod, there could be a mounting conflict for the BSS pod.

Alternative C is also quite flexible in that it is applicable to any aircraft, it minimizes the equipment required in the instrumentation pod and can utilize a smaller pod. It further has the added potential of being able to accomplish real time bomb scoring through the addition of a processor at the ground terminal. The prime disadvantage of the system is that it is range restricted in that the aircraft and ground station must be in sight of each other. It furthermore requires a ground terminal, however, the ground terminal can easily be packaged to be air transportable.

An alternate A or B selection may also force a selection of A and B. Since alternate A is only applicable for X-set equipped aircraft, alternate B may then be required to score non - X-set equipped aircraft. Similarly, with an alternate B selection, if an aircraft is provided its navigation data from equipment mounted in a pod, then a second pod location is required for the BSS and may force the use of the smaller alternative A for this application where two large pods could not be accommodated by the aircraft.

Unlike alternatives A and B, alternative C requires only a small pod and is independent of the equipment on the aircraft. Additionally, the cost to implement an A and B pod, or two B pods is approximately the same in cost as implementing two C pods.

5.2 Recommendations

1. Because alternate C (transponded signals to a ground station):

   a) requires one-third weight, power, and volume (compared to alternate B)

   b) is less costly when more than one pod is implemented, (compared to alternate B)

   c) has the potential for real time bomb scoring assessment, and

   d) is applicable to any aircraft,

   It is recommended that alternate C be implemented for the Bomb Scoring System.

2. Because alternate A is only applicable to X-set equipped aircraft, it is not recommended for implementation. This alternative could require that other alternatives also be implemented for the Non-X-Set equipped aircraft at a higher total system cost.

	Characteristics	Alternate A (X-Set Equipped A/C)	Alternate B (X-Set in BSS Pod)	Alternate C (Transponded Signals to G.T.)
PHYSICAL	Aircraft weight power size	 430 lbs. 485 watts small pod	 1135 lbs. 1515 watts large pod (600 gal)	 536 lbs. 480 watts small pod
OPERATIONAL	Capable of Real Time Assessment	no	no	yes(added processor required)
	Adaptable to wide variety of aircraft	no (must have X-set)	yes (must have capability of carrying pod)	yes
	Independent of Target Location	yes	yes	no (Aircraft must be in range of ground terminal: 80 nmi at 5000 ft. altitude)
PERFORMANCE	Independent Assessment	no (uses same navigation data as aircraft)	yes	yes
	Ability to Resolve Ionospheric Propagation Errors	excellent	excellent	good (requires interpolation from ground terminal/satellite geometry to aircraft/satellite geometry)
COST	1 Pod	$550 K	$1,190 K	$1,430 K
	2 Pods	$715 K	$1,735 K	$1,665 K
	3 Pods	$880 K	$2,280 K	$1,900 K

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SAC	GPS transponder
Bomb Scoring Systems	Aircraft instrumentation
GPS	
Range Instrumentation	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This volume summarizes the work performed for the Air Force addressing a GPS/SAC Bomb Scoring System using GPS Phase I.

This report describes the evaluation and comparison of three Bomb Scoring System (BSS) techniques which use the GPS satellites to assist in the accuracy assessment. The objective of each system is to provide an independent evaluation of the aircraft's navigation/bombing accuracy and is therefore supplemental to the aircraft's navigation system.

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Alternate A considers the use of on-board GPS and other aircraft instrumentation to derive the evaluation. Since it uses on-board equipment, alternate A has the least impact on the aircraft's performance. It is, of course, limited in its application to GPS-equipped aircraft.

Alternate B considers the use of totally redundant equipment, carried in a separate BSS pod to derive the independent assessment, and is similar in nature to the GPSTP.

Alternate C considers the use of transponded data to a ground station in order to minimize the aircraft-carried equipment , therefore minimizing the impact to the aircraft's performance.